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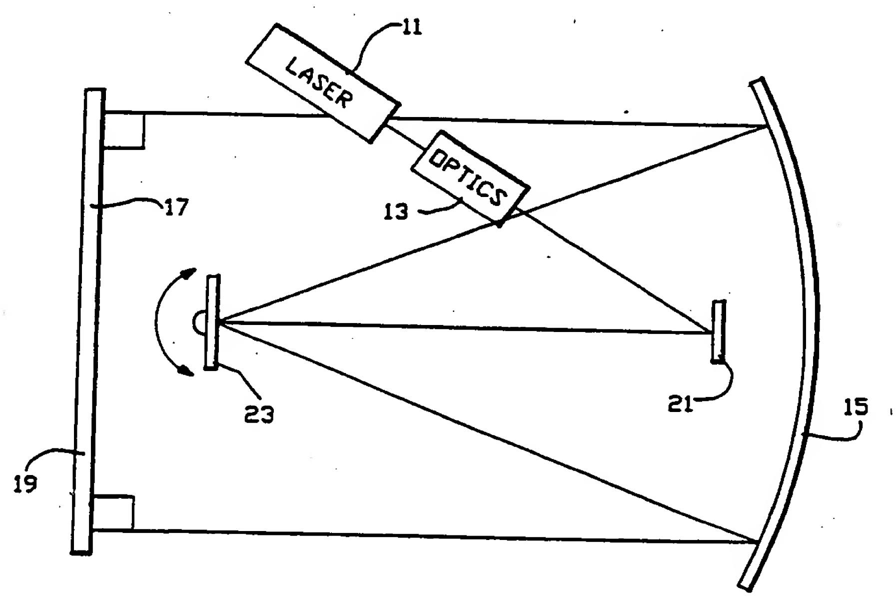
With international search report.
With amended claims and statement.

(54) Title: OPTICAL SCATTER IMAGING



(57) Abstract

A particle imager and method for imaging particles on surfaces of substrates (19). A reflective suface (17) is scanned by a collimated light beam (57) and particles on the surface are detected by the scattered light caused by the particles. During a scan path (81) the intensity of the scattered light is measured forming intensity traces (91) and location addresses for the detected particles. Data from each scan path is stored in memory. A three-dimensional surface map (95) is formed from the data stored in memory. The intensity traces for a particle (71) when combined together in the surface map form an intensity profile (97, 99, 101) or signature of the particle. These signatures may then be compared to known particle signatures to determine characteristics of the detected particle.

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Description

Optical Scatter Imaging

Technical Field

The present invention relates to imaging particles on a surface by scanning the surface with a light beam.

Background Art

Detecting particles on surfaces of substrates is of prime importance to integrated circuit manufacturers. This is increasingly true with the lowering of minimal line widths of some devices to less than one micron. As line widths have decreased, so too have the critical particle sizes decreased, the critical particle size being a particle dimension which will cause a problem on a line of minimum width. For example, a particle size one tenth that of the minimum line width on a wafer surface can in some cases disable the circuit. Therefore, very small particles of less than one micron need to be detected. Moreover, as wafers increase in size to 200 mm at some manufacturers, it is even more important to achieve high yields. To obtain high yields manufacturers currently take before and after particle counts as a wafer progresses through each piece of processing equipment, or through each unit process, thereby hoping to locate the sources of the contaminating particles. This is both costly and time consuming.

One prior art method for detecting surface particles involves scanning the wafer surface with a laser beam and then detecting the light scattered by particles or defects. From data obtained during the scan a two-dimensional surface defect map is created. Such a map shows the location and approximate size of the defects on the surface. An example of a scanner of this type is found in U.S. Pat. No. 4,378,159 to Galbraith and assigned to the assignee of this invention. Although prior

art methods may determine particle count, location, and approximate size they usually do not determine other characteristics of the particles such as shape, index of refraction, surface texture, and composition. Such information could be used to identify sources of particles, which is important in maintaining clean wafers.

In U.S. Pat. No. 4,555,179, to Langerhole, entitled "Detection and Imaging of Objects in Scattering Media by Light Irradiation", a system is disclosed which detects subsurface objects by measuring the light power scattered backward from a medium that has been scanned by a strong collimated light beam. The subsurface objects are detected by the differential variation of the received light power.

It is an object of the present invention to devise an analysis tool which would more accurately image microscopic particles on a substrate surface.

Another object of the invention is to determine particle characteristics and thereby help reduce the number of surface particles and defects on a substrate surface, such as semiconductor wafers.

Disclosure of the Invention

The above objects have been met with an apparatus and method for surface scanning in which a three-dimensional amplitude signature is generated for each particle or defect. A surface, such as a semiconductor wafer or blank photomask, is scanned with a beam. Surface particles and defects scatter light from the beam. A detector measures the intensity of the scattered light. Succeeding scan lines preferably spaced less than the characteristic beam width apart cause overlapping traces for the same particle or defect. These traces when combined form a three-dimensional amplitude representation, like an image, for each particle or defect, almost like a vertical slice image of mountainous terrain in a topographic map. The amplitude representations can then be analyzed and compared with models and test data to

determine characteristics of the particles or defects such as size, shape, index of refraction, surface texture, and composition, thereby creating particle signatures. Knowing these characteristics would then lead to identifying the source of the contaminating particles and defects. By combining the signatures and location data generated during the scanning process a three-dimensional topographic map of defects can be formed and displayed. Alternatively, a three-dimensional map may be formed which incorporates the characteristics determined from the particle signatures. For example, the size, shape and surface texture of the particles and defects together with their locations may be used in forming a map identifying types of particles, as well as locations. By analyzing the three-dimensional particle signatures and surface maps, the source or sources of contamination may be identified in one complete scan, thus reducing the number of scans required to specify the cleanliness of the complete fabrication process. Moreover, knowing the source or sources of contamination will help effect steps to eliminate those sources, thus reducing the number of particles and defects on a wafer surface.

Brief Description of the Drawings

Fig. 1 is a plan view of an optical configuration for generating a scanning beam in accord with the present invention.

Fig. 2 is a plan view of an optical arrangement for collecting light from the apparatus of Fig. 1.

Fig. 2A is a perspective view of a test wafer having a plurality of sampling points in known positions.

Fig. 3 is a block diagram of the particle imager and characteristics correlator of the present invention.

Figs. 4A and 4B are graphs of a Gaussian beam intensity distribution in conjunction with an enlarged top view of a wafer surface showing a particle and a

plurality of scan paths by which the particle is detected using the apparatus of Figs. 1 and 3.

Fig. 5 is a graph of a plurality of traces generated during the five scan paths of Fig. 4.

Figs. 6 and 6A are enlarged plan views of scattered light intensity maps using the apparatus of Figs. 1 and 2.

Best Mode for Carrying Out the Invention

A. Description of Surface Scanner

With reference to Fig. 1, laser 11, such as an argon ion laser, generates a beam which is prefocused by optical elements 13, typically one or more lenses, to a point beyond the spherical mirror 15, namely the surface 17 of a wafer 19 being inspected. After passing through optics 13, the laser beam impinges upon a small fixed mirror 21 which folds the light path and directs the beam toward scanning mirror 23. The scanning mirror 23 is supported on an arm connected to a motor which rocks the mirror at its natural frequency of vibration. Such mirrors are known as scanning resonant mirrors and the natural frequency of vibration is specified by the manufacturer.

The scanning mirror is aligned at a slight tilt relative to the incident beam so that the scanning beam describes a shallow cone in space, but will follow a straight line path after reflection from the spherical mirror 15. The purpose of the spherical mirror's curvature is to cancel the effective field curvature of the prefocused beam to produce an essentially planar image field at surface 17. The scanning mirror 23 is optically flat and its axis of rotation is not perpendicular to the incoming beam in order to generate the shallow cone in the reflected beam, previously mentioned. This optical arrangement permits generation of about 100 micrometer scan spot on a flat image field with a path straightness

within 10 micrometer over a total scan distance of 200 millimeters. The scan is nearly telecentric.

With reference to Fig. 2, a telecentric input beam 31 is seen passing into an internally reflecting elliptical cylinder 33 through a linear slot 35 whose length is parallel to the scan direction, i.e. in a plane perpendicular to the paper of the drawing. The narrow slit 35 allows egress of light specularly reflected from the reflective surface 17 of wafer 19. Beam 31 impinges along a focal line 37 extending into and out of the plane of the paper of the drawing. Focal line 37 is one of two foci of the elliptical cylinder 33. The second focal line 39 is a line where input ends of fiber optic fibers 41 are aligned. Thus, any light which is scattered from a dirt particle or flaw along the scanning line 37 will be reflected to the second scan line 39 and be input into fibers 41. Since the scattering is coming from irregular surfaces, the light appearing line 39 does not form a true optical image of the particle or flaw. Rather, the light along line 39 is representative of the scattered intensity from the particle or flaw. If the particle or flaw is large, more light will be scattered than if the particle is small. Light entering the fibers 41 is transmitted to a detector 43 which may be a photomultiplier tube. After a wafer is scanned along a line, the wafer is advanced slightly by wheels 45 or by another support mechanism. By slightly advancing the wafer, another line may be scanned. By scanning different lines which are parallel and slightly spaced apart, an entire wafer may be scanned. Differences between small particles and flaws such as cracks or spurious signals such as noise may be interpreted in accord with the particle detection method set forth in U.S. Pat. No. 4,766,324 to S. Saadat, assigned to the assignee of the present invention.

With reference to Fig. 2A, a wafer 19 is shown with a plurality of sampling points at which the scattered signal is sampled on the wafer. The wafer is

placed between light marker pins 53 and 55 at opposite sides of the wafer and aligned with the scanning line of the optical system. As beam 57 is swept across the wafer, the amplitude of the scattered signal is sampled at specific positions 57a, 57b, 57c so as to cover the wafer with a regular array of sampling points 51 which are preferably spaced a uniform distance apart. The start of the array is referenced to the marker pins 53 and 55.

The start of the array is timed to coincide with the transit of the beam across one of the marker pins (say 53) as the beam moves toward the other marker pin 55. the start signal is produced by a light detector placed behind either marker which senses the transit of the beam across the timing marker. When light from the beam is first received at the detector behind marker 53, as the beam passes over the edge of pin 53, it initiates a counter which counts pulses from an accurate 50 megahertz clock.

The output of the counter is continuously compared to a series of predetermined values which are stored in a random access memory. When the counter value equals the stored value, a pulse is issued to the sampling circuit which samples the instantaneous amplitude of the scatter signal received at the detector. The predetermined values which are compared to the counter output are selected so that the scatter signal is sampled at precisely equal distances apart or known positions on the wafer under test. The separation between sampling points is approximately 26 microns.

Any errors in position of the sampling points can be corrected by calibrating the position of the beam with respect to the marker pins using a standard wafer having scattering sources whose relative positions are known to very high accuracy. The apparent position of these scattering sources is measured using the initial table of sampling points. The difference between the apparent positions and the known positions of the scattering sources is used to generate an error function

which is used to modify the predetermined values which are stored in the random access memory. This generates a new table of predetermined values which corrects for irregularities in the motion of the beam and defines the position of the sampling points to the same accuracy as the reference scattering sources on the standard wafer.

By this means one is able to establish a very accurate coordinate system in the X axis where the exact position of a scattering source on a wafer under test is known simply by counting the number of sample points from the start of the marker pin 53 or 55.

The Y position is established by counting the number of sweeps from the start of the wafer. This establishes an orthogonal set of XY coordinates which allows one to access and store data from any point of the wafer and store a microscan of a small section of the wafer in that area, without incurring any distortion of the stored image.

B. Particle Modeling

In Fig. 3, scattering light data coming from a scan line are stored sequentially in first memory 44. Scattering data includes intensity data and corresponding addresses made up of a scan line number and a beam location address. As a particle is scanned by the beam, the intensity of the scattered beam, exceeding a preset threshold, is digitized and sent to first memory 44. This is termed pulse data. Under control of a timing control 46 the X, Y- addresses for light scattering signals, i.e. pulse data are generated. All of the data from each scan line is stored in first memory 44.

Pulse data may then be sent from first memory 44 to a signal processor 48 which analyzes and processes the pulse data and corresponding addresses into a graphical representation of the wafer surface. In an embodiment of the present invention the graphical representation of the surface is a three-dimensional surface map containing the pulse data and addresses from each scan

line. All or portions of this three-dimensional surface map may then be selected for display from a display command input device 50, such as a keyboard. Once selected, the pulse data representing a selected area to be displayed is sent to an output buffer 58 for temporary storage. The data are then sent to a display device 60, where an image of the wafer surface is created. Typically, the display device 60 is a video display terminal or a printer. Alternatively, data is sent from first memory 44 to data comparator 54 which compares the pulse data with known models or test data stored in data bank 52. With a positive comparison a characteristic or characteristics of the scattering particle may be determined. Particle characteristic data are then stored in second memory 56. A graphical representation of the determined characteristic data, stored in second memory 56, may then be determined by the signal processor 48. The representation may be a three-dimensional surface map showing size, shape and surface texture of the detected particles or the representation may have another graphical form, which is useful for viewing. When selected by the display command input device 50 the graphical representation of the particles characteristics may be displayed in like manner as previously discussed.

In Figs. 4A and 4B, a scanning laser beam 61 typically has a Gaussian intensity distribution

$$I(x) = I_o \exp(-(W / \sqrt{2x})^2)$$

where I_o is a peak intensity at the center of the beam 63 and W is the full width measured at $1/e^2$ of the peak intensity. Typically, the scanning beam has a full width, as represented in Fig. 4A by arrows A-A, of about 100 micrometers. Thus the beam 61 has a width substantially larger, usually four to six times larger, than the scan line separation.

With reference to Figs. 4A, 4B and 5 a particle 71 is detected during five scan paths 73-81. Scan path

94 did not detect particle 71. Arrows B indicate the distance between scan paths. A typical space is 20 μm. An intensity trace is generated during each detection 85-93. Dashed line 83 in Fig. 4A indicates the peak intensity of the scanning beam 61 that hits particle 71 during scan path 79. Trace 91 is generated during scan path 79. Similarly, intensity trace 85 is generated during scan path 73 and intensity trace 87 is generated during scan path 75 and so on. Generally, the first detection of a particle will result in a lower intensity trace than the succeeding trace. The highest trace will occur when the center of the scanning beam 63 is nearest to being directly over the particle as is the case for trace 89 during scan path 77. As the center of the beam moves further away from the particle the traces become smaller until the particle is no longer detected. Combining pulses 85-93 of particle 71 together forms an amplitude profile of the scattered light. This profile has a shape much like that of a mountain on a topographical map.

In Figs. 6 and 6A, a surface map 95 contains three scattered light amplitude profiles 97, 99, and 101. Two views of the amplitude profiles 97-101 are shown. Each profile is made up of five intensity traces, which were generated while scanning the surface 96, one scan line at a time. Each of the profiles is a scattering light intensity image of a particle which was detected during the scanning process. The mountainous-like shape of a profile is an amplitude representation of light scattered from the particle. When this amplitude data is combined with other data a distinctive particle signature is derived. The other data may include size, shape, surface texture, index of refraction and the like. This other data is established by comparison with particles of known composition and qualities. The test data from these particles is used to form model particles. Identifying the nature of the particles would then lead to the discovery of the source or sources of the particles.

Claims

1. A method for particle imaging comprising,

scanning a surface with a collimated light beam having a characteristic beam width, said scanning having spaced apart scan lines,

generating X, Y- addresses during said scanning for locations of said beam on said surface,

measuring a scattering intensity of said light beam from said surface for each X, Y- address,

storing said X, Y- addresses and corresponding scattered light intensity data in memory, and

mapping said stored data to produce three-dimensional intensity representations of said scattering.

2. The method of claim 1 wherein said scan lines are spaced a distance less than a beam width apart.

3. The method of claim 1 wherein said processing includes forming a three-dimensional surface map of said surface from said intensity representations and corresponding data addresses.

4. The method of claim 3 further comprising displaying a selectable portion of said three-dimensional surface map.

5. The method of claim 1 further comprising determining characteristics of said particles and defects by correlating said intensity representations with known models and test data.

6. The method of claim 5 wherein said determining of said characteristics employs at least two characteristics selected from the group of size, shape, index of refraction, surface texture, and composition.

7. A method for particle imaging and characteristics determining comprising,

scanning said surface with a collimated light beam having a characteristic beam width, said scanning having spaced apart scan lines, scattering of said light beam from said surface having its intensity trace measured when scattering amplitude is above a threshold value, an X, Y- address being generated during said scanning for locations where the scanning amplitude exceeds the threshold,

storing said X, Y- addresses and corresponding scattered light intensity data in memory,

mapping said data to produce three-dimensional intensity representations of said scattering and to develop a three dimensional surface map by employing said intensity representations,

displaying a selected portion of said three dimensional surface map, and

determining characteristics of said particles and defects by comparing said intensity representations with known models and test data.

8. The method of claim 7 wherein said scan lines are spaced a distance less than said beam width apart.

9. The method of claim 7 wherein said determining ot characteristics employs at least two characteristics selected from the group of size, shape, index of refraction, surface texture, and composition.

10. The method of claim 9 wherein said mapping includes forming three-dimensional surface maps incorporating said characteristics.

11. The method of claim 10 wherein said displaying includes said three-dimensional maps incorporating said characteristics.

12. A particle imager and intensity comparator for use with a surface scanner comprising,

a surface scanner of the type having scanning means for inspection of a surface and generating addresses and scattering amplitude data from particles on said surface,

means for receiving said addresses and corresponding scattering amplitude data on a current scan line,

means for storing said addresses and data, some of said addresses matching addresses stored from previous scan lines, other of said addresses corresponding to new particle detections,

means for combining said addresses and amplitude data to produce three-dimensional amplitude representations relating to said particles,

means for forming three-dimensional surface map from said amplitude representations and said addresses,

means for displaying said surface map in association with an image processor, said image processor having means for selecting portions of said surface map for display.

13. The particle imager and intensity comparator of claim 12 further comprising means for comparing said amplitude representations with known models and test data.

AMENDED CLAIMS
[received by the International Bureau on 12 August 1991 (12.08.91); original claims 2 and 8 cancelled; original claims 1, 7 and 12 amended; other claims unchanged but renumbered (3 pages)]

1. A method for particle imaging comprising,

scanning a surface with a collimated light beam having a characteristic beam width, said scanning having adjacent scan lines spaced apart by a distance less than said characteristic beam width thereby causing overlapping traces,

generating X, Y- addresses during said scanning for locations of said beam on said surface,

measuring a scattering intensity of said light beam from said surface for each X, Y- address,

storing said X, Y- addresses and corresponding scattered light intensity data in memory, and

mapping said stored data to produce three-dimensional, topographic, intensity representations of said scattering.

2. The method of claim 1 wherein said processing includes forming a three-dimensional surface map of said surface from said intensity representations and corresponding data addresses.

3. The method of claim 2 further comprising displaying a selectable portion of said three-dimensional surface map.

4. The method of claim 1 further comprising determining characteristics of said particles and defects by correlating said intensity representations with known models and test data.

5. The method of claim 4 wherein said determining of said characteristics employs at least two characteristics selected from the group of size, shape, index of refraction, surface texture, and composition.

6. A method for particle imaging and characteristics determining comprising,

scanning said surface with a collimated light beam having a characteristic beam width, said scanning having adjacent scan lines spaced apart by a distance less than said characteristic beam width thereby causing overlapping traces, scattering of said light beam from said surface having its intensity trace measured when scattering amplitude is above a threshold value, an X, Y-address being generated during said scanning for locations where the scanning amplitude exceeds the threshold,

storing said X, Y- addresses and corresponding scattered light intensity data in memory,

mapping said data to produce three-dimensional, topographic, intensity representations of said scattering,

displaying a selected portion of said three dimensional topographic representations, and

determining characteristics of said particles and defects by comparing said intensity representations with known models and test data.

7. The method of claim 6 wherein said determining of characteristics employs at least two characteristics selected from the group of size, shape, index of refraction, surface texture, and composition.

8. The method of claim 7 wherein said mapping includes forming three-dimensional surface maps incorporating said characteristics.

9. The method of claim 8 wherein said displaying includes said three-dimensional maps incorporating said characteristics.

10. A particle imager and intensity comparator for use with a surface scanner comprising,

a surface scanner of the type having scanning means for inspection of a surface and generating addresses and scattering amplitude data from particles on said surface, said scanning means including a beam scanner having a characteristic beam width and scan lines mutually spaced apart by a distance less than said characteristic beam width thereby causing overlapping traces,

means for receiving said addresses and corresponding scattering amplitude data on a current scan line,

means for storing said addresses and data, some of said addresses matching addresses stored from previous scan lines, other of said addresses corresponding to new particle detections,

means for combining said addresses and amplitude data to produce three-dimensional amplitude representations relating to said particles,

means for forming three-dimensional topographic surface map from said amplitude representations and said addresses,

means for displaying said surface map in association with an image processor, said image processor having means for selecting portions of said surface map for display.

11. The particle imager and intensity comparator of claim 10 further comprising means for comparing said amplitude representations with known models and test data.

STATEMENT UNDER ARTICLE 19

The difference between the amended claims 1, 6 and 10 (original claims 1, 7 and 12) and the Galbraith prior art is that by using a detector of the type described in Galbraith, plus signal processing electronics and closely adjacent scan lines, it is now possible to create topographic representations of scattered light images. This enables a Galbraith detector to create particle images which look like microscope images, something not achieved in the prior art using scattered light.

In the remaining prior art, various types of data plots are shown, some of which may be said to be three dimensional. However, it is significant that the prior art does not teach use of scattered light for three dimensional topographic images, as in the amended claims. Rather, the prior art is conspicuously silent on use of scattered light. Rather elaborate and interesting schemes have been used as alternative inspection devices, including the phase imaging/magnitude imaging of laser induced acoustic waves in the Busse reference; dual color comparison imaging in the Shiragasawa et al. reference; dual image natural light and artificial reflected light comparisons in the Yamane et al. reference. Taking all of these teachings into account, there is nothing to suggest that one could construct the topographic scattered light images as set forth in the amended claims. The significant advantage of the present invention is that now scattered light three dimensional images resemble images which were usually obtained from a conventional microscope in the prior art.

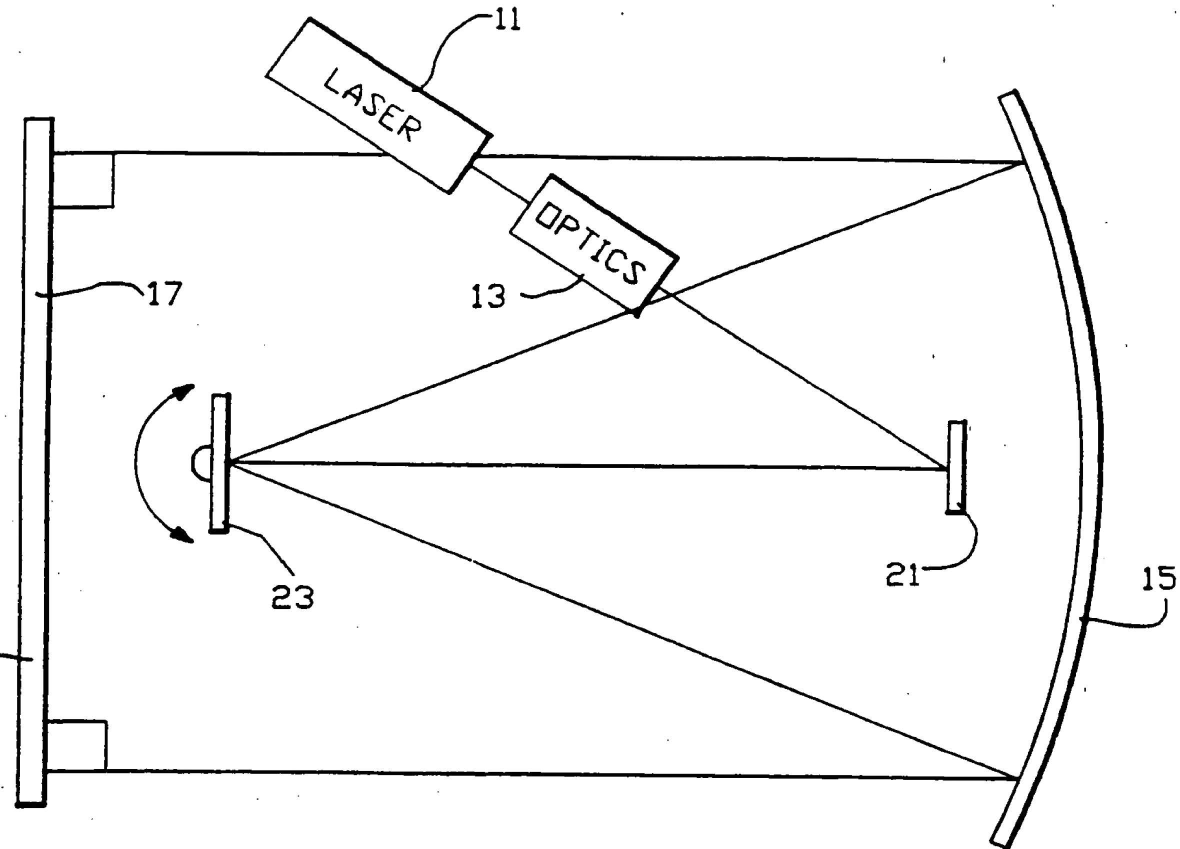

FIG.-1

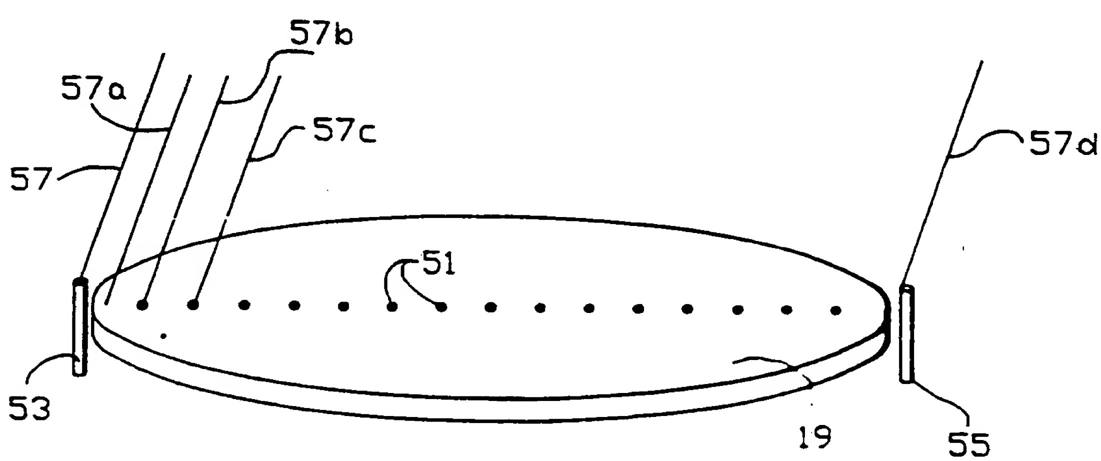

FIG.-2A

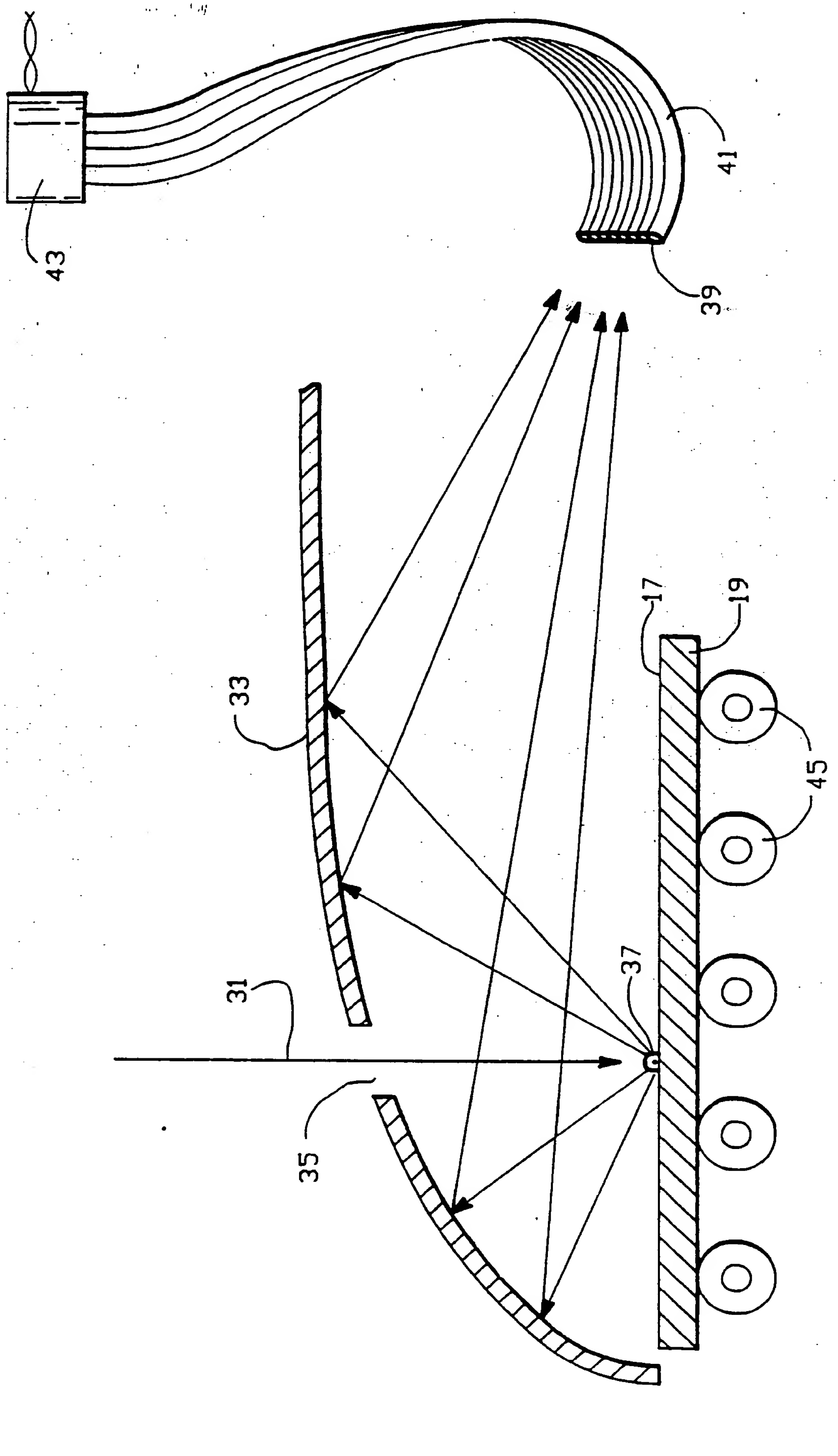

FIG.-2

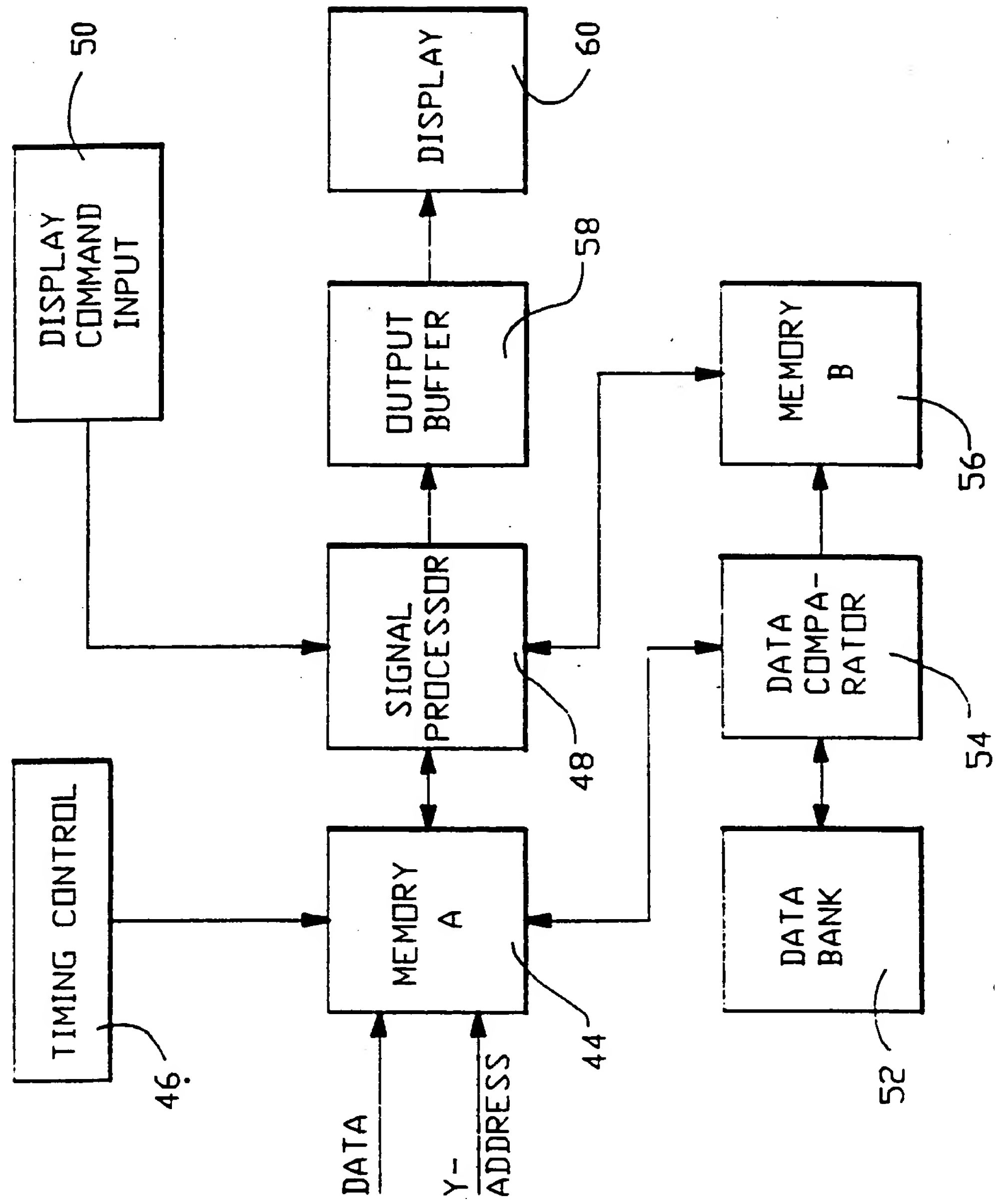
DISPLAY COMMAND INPUT
50
DISPLAY
60
OUTPUT BUFFER
58
MEMORY B
56
SIGNAL PROCESSOR
48
DATA COMPA-RATOR
54
TIMING CONTROL
46
MEMORY A
44
DATA BANK
52
DATA
Y-ADDRESS

FIG.-3

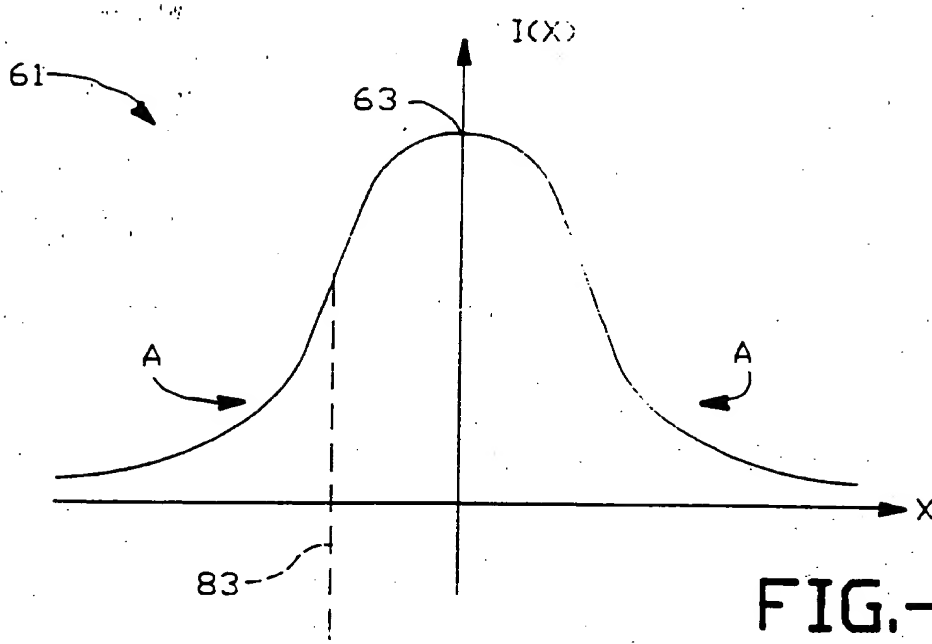

FIG.-4A

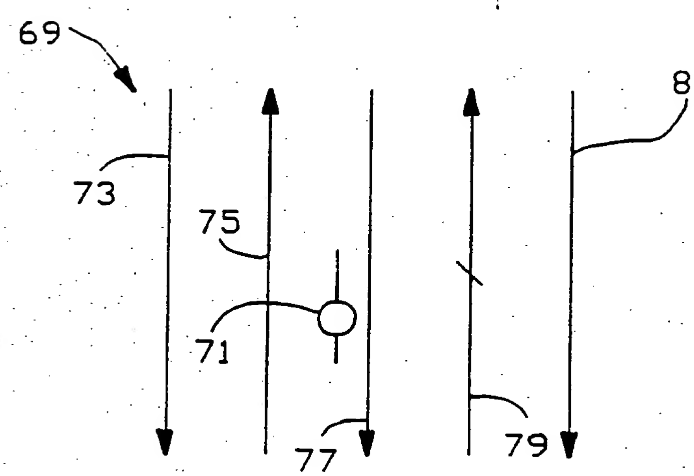

FIG.4B

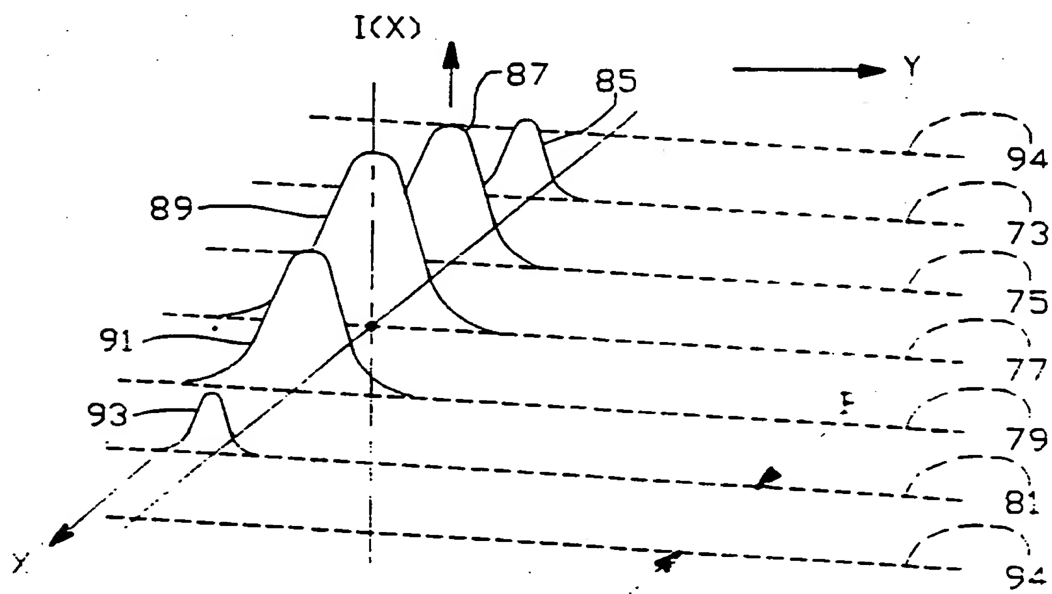

FIG.-5

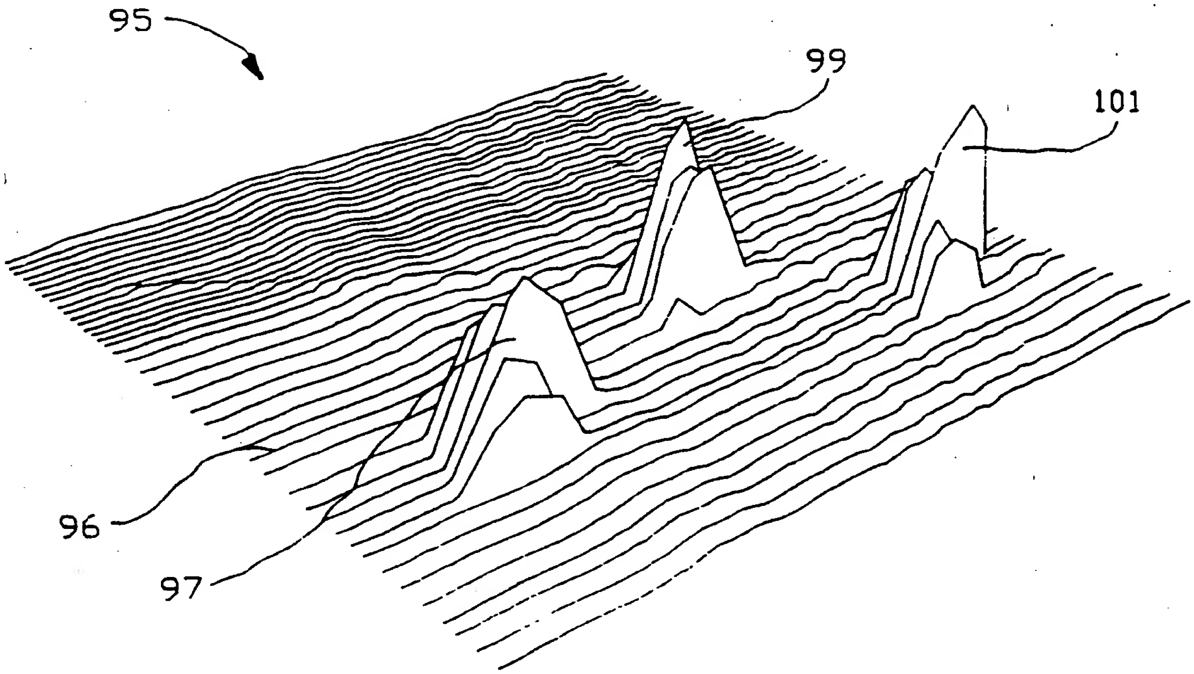

FIG.-6

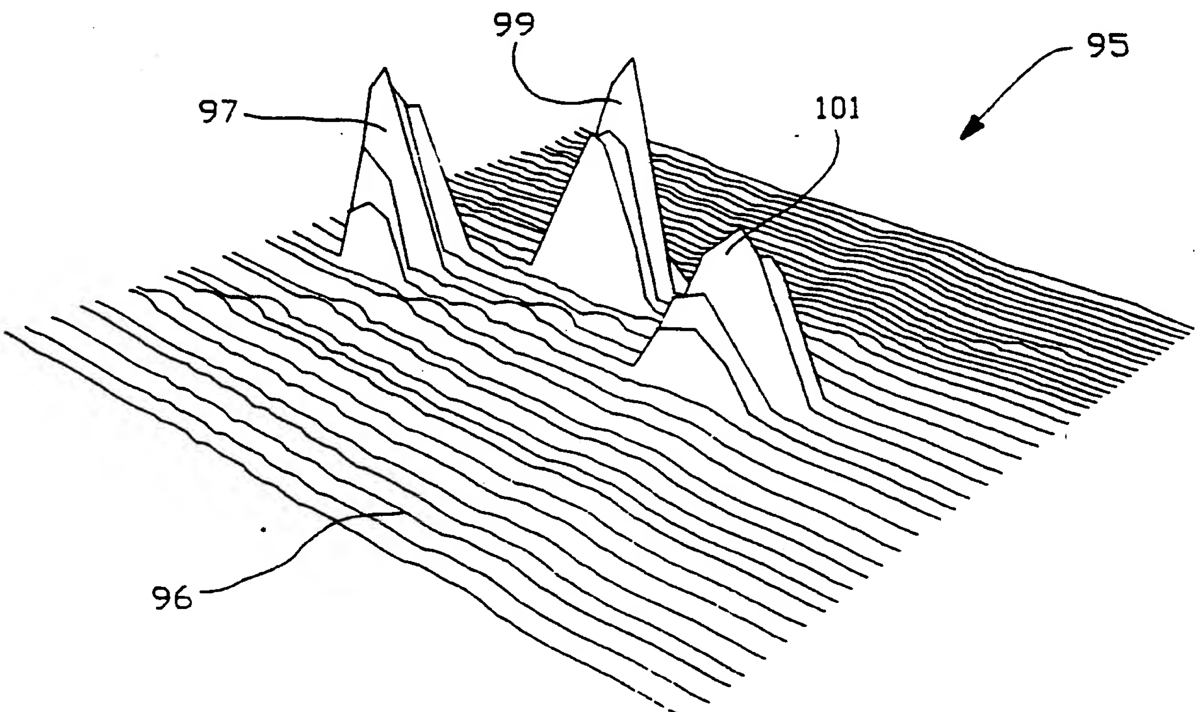

FIG.-6A

INTERNATIONAL SEARCH REPORT

International Application No PCT/US91/01445

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[5] G01N 21/47

U.S. Cl. 356/237

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S. Cl.	356/237 382/8

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No [18]
Y	US,A 4,378,159 GALBRAITH 29 March 1983 (29.03.83) (Note column 4, lines 18-34)	1-13
Y	US,A 4,759,072 YAMANE et al. 19 July 1988 (19.07.88) (Note Figures 5 and 6)	1-13
Y	US,A 4,736,159 SHIRAGASAWA et al. 05 April 1988 (05.04.88) (Note Figure 6)	1-13
Y	Applied Physics Letters, vol. 36, no. 10 15 May 1980 (15.05.80) BUSSE et al. "Subsurface imaging with photoacoustics" pages 815-816. (Note Figure 3)	1-13

* Special categories of cited documents: [15]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
21 May 1991 (21.05.91)	19 JUN 1991
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	R. A. Rosenberger

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